

## **REAL-TIME WEB INSPECTION METHOD AND APPARATUS USING COMBINED REFLECTED AND TRANSMITTED LIGHT IMAGES**

### **BACKGROUND**

This development relates generally to a web inspection method and apparatus using an improved lighting and camera arrangement. It is described herein with reference to a web inspection method and apparatus for a flexible imaging web such as, e.g., a photoreceptor web used to manufacture photoreceptor belts for electrophotographic imaging systems, but it is not intended to be limited to inspection on any particular type of web material.

In the art of electrophotography, an electrophotographic member comprising a photoconductive insulating layer on a conductive layer is imaged by first uniformly electrostatically charging the imaging surface of the photoconductive insulating layer. The member is then exposed to a pattern of activating electromagnetic radiation such as light, which selectively dissipates the charge in the illuminated areas of the photoconductive insulating layer while leaving behind an electrostatic latent image in the non-illuminated area. This electrostatic latent image may then be developed to form a visible image by depositing finely divided electroscopic toner particles on the surface of the photoconductive insulating layer. The resulting visible toner image can be transferred to a suitable receiving member such as paper. This imaging process may be repeated many times with reusable photoconductive insulating layers.

The electrophotographic member is often in the form of a flexible multilayered photoreceptor belt comprising a substrate, a conductive layer, an optional hole blocking layer, an optional adhesive layer, a charge generating layer, and a charge transport layer and, in some embodiments, an anti-curl backing layer.

As more advanced, higher speed electrophotographic copiers, duplicators and printers have been developed, the electrical and mechanical performance requirements for photoreceptor belts have become more demanding. New digital color and other image-producing products cannot tolerate defects that have been acceptable for previous generation imaging apparatus, such as analog or "light-lens" copiers.

These heightened electrical and mechanical performance requirements are not met when certain defects are located on the surface of or within one or more of the layers of the multilayered belt photoreceptors. These defects are caused by the presence of dirt particles on the substrate, conductive layer, optional hole blocking layer, optional adhesive layer, charge generating layer, charge transport layer and/or optional anti-curl backing layer. Thus for example, particles of dirt (particulate debris) residing on an uncoated or coated substrate surface during application of coatings to form an electrostatographic imaging member, such as a photoreceptor, can cause bubbles or voids to form in the various applied coating layers. It is believed that the dirt particles behave in a manner similar to a boiling chip that initiates solvent boiling at the location of the particle. This local boiling problem is aggravated when a coating solution is maintained near the boiling point of the coating solvent during deposition of the coating or during drying. The formation of bubbles in a coating is particularly acute in photoreceptor charge generation layer coatings and in charge transport layer coatings. Also, dirt particles tend to trap air during application of a coating and the trapped air expands during drying to form an undesirable bubble in the coating. Further, any dirt particles residing on one or both surfaces of an electrophotographic imaging member web substrate or coating thereon can adversely affect adjacent surfaces when the web is rolled up into a roll

because the dirt particles cause impressions on the adjacent web surfaces. Because these undesirable impressions can be repeated through more than one overlapping web layer, large sections of a coated web must be scrapped, and this result is highly undesirable.

It should be apparent from the foregoing that it is highly desirable to identify defects in a photoreceptor web before the web is cut and formed into an endless imaging belt. If the defects are identified in advance, it is often possible to cull the defective region from the web so that same does not form part of a finished photoreceptor belt, or to ensure that the defective part of the web is used to manufacture a photoreceptor belt usable for an application where the defect(s) will have no undesired consequences.

It is known to use human inspectors alone or in combination with automated web inspection system in an effort to identify web defects. In one known system, a human operator visually inspects the translucent web as it passes over a light-box. In another embodiment, machine-vision systems are used to acquire images of web moving therepast, and these images are processed according to defect-identification algorithms in an effort to provide an automated web inspection method and apparatus. In known systems of this type, reflected light images and transmitted light images are acquired sequentially and not simultaneously. As such, with conventional web inspection schemes, it is not possible to perform real-time acquisition and analysis of combined transmitted/reflected light images. With conventional system, the sequentially acquired images must be combined off-line, and then processed for image identification and classification. Obviously, this is highly undesired, especially in a process where defects in the web are marked immediately downstream from the inspection process and/or in a process where the

web is cut for into sections to be formed into end-products, e.g., photoreceptor belts, immediately downstream from the inspection process.

In light of the foregoing issues, it has been deemed desirable to provide a real-time web inspection method and apparatus using combined reflected and transmitted light images as disclosed herein.

## **SUMMARY**

In accordance with a first aspect of the present development, a web inspection method comprises projecting light from a source to be incident on a select portion of a web that is moving in a down-web direction and that extends laterally to define a width in a cross-web direction. Reflected light from the source that is reflected by the select web portion is captured and a digital image of the reflected light is derived. Simultaneously with the step of capturing reflected light, transmitted light from the source that is transmitted through the select web portion is also captured, and a digital image of the transmitted light is derived. The reflected light digital image and the transmitted light digital image are merged to derive merged image data that represent both the reflected light and the transmitted light. The merged image data are used to identify defects in the web.

In accordance with another aspect of the present development, a web inspection apparatus comprises first and second web supports for movably supporting an associated web moving in a down-web direction. A light source outputs a light pattern adapted to be incident on a select free-span, unsupported portion of the associated web that is located between the first and second web supports. A reflected light image capturing system is provided for imaging the select portion of the associated web based upon light from said source reflected by the

select web portion. A transmitted light image capturing system is also provided for imaging the select portion of the associated web based upon light from the source transmitted through the select web portion, wherein the reflected light image capturing system is registered with the transmitted light image capturing system so that the reflected light image capturing system and the transmitted light image capturing system are adapted to simultaneously image the select portion of the associated web in terms of reflected and transmitted light, respectively.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

The development comprises various components and arrangements of components, and comprises various steps and arrangements of steps, preferred embodiments of which are illustrated in the accompanying drawings that form a part hereof and wherein:

Figure 1 is a diagrammatic illustration of a real-time web inspection method and apparatus using combined reflected and transmitted light images;

Figure 2 provides a detailed illustration of the web inspection station of Figure 1; and,

Figure 3 provides further detailed illustration of the web inspection station and a method for real-time web defect detection.

### **DETAILED DESCRIPTION**

Figure 1 illustrates a real-time web inspection method and apparatus using combined reflected and transmitted light images in accordance with the present development. In the illustrates embodiment, a web **W**, e.g., a photoreceptor web, is dispensed from an upstream supply roll or other source **R1** and is collected at a

storage roll or other storage location **R2**. The web **W** thus moves from the supply roll **R1** downstream in a down-web direction to the storage roll **R2** as indicated by the arrow **DW**. For ease of reference herein, the term “cross-web” is intended to denote a direction perpendicular or otherwise transverse to the down-web direction **DW** and parallel to the plane of the web **W**.

In the illustrated embodiment, the web **W** moves from the storage roll **R1** through a web cleaning station **S1** for remove contaminants on its upper surface **WU** and/or lower surface **WL** via conventional means such as cleaning rolls and/or other contact or non-contact means. The web **W** then passes through a web inspection station **S2** where it is inspected for defects, and then to web marking station **S3** where any defects in the web are marked with labels, ink or any other suitable marking means. In one embodiment, the web marking station **S3** is replaced or supplemented by a defect culling station **S3'** where the defects are cut from the web **W** before the web is cut into sections that are formed into end-products. The web inspection station **S2** and web marking station **S3** are operably interconnected to an image processing unit **IPU** that receives data from the web inspection station **S2** and sends data to the web marking station **S3** to indicate the portions of the web **W** to be marked or culled. As indicated with broken lines, data can optionally also flow from the image processing unit **IPU** to the web inspection station **S2** to control same and/or from the web marking station **S3** to the image processing station **S3** for feedback purposes or the like. In general, the web inspection station **S2** and image processing unit **IPU** cooperate to perform real-time web inspection using combined reflected and transmitted light images in accordance with the present development. The web cleaning station **S1**, marking station **S3** and/or defect culling station **S3'** are optional but at least one of these is typically provided and used as part of the real-

time web inspection method/apparatus.

The web inspection station **S2** is disclosed in further detail with reference to Figure 2. There, it can be seen that the web inspection station **S2** comprises first and second web support members such as idler rolls **I1,I2** that movably support the web **W** so that an unsupported free-span web portion **FS** extends therebetween. The supply and storage rolls **R1,R2** (Fig. 1) and/or the web support members **I1,I2**, control the speed at which the web **W** moves in the down-web direction **DW** and control the tension under which the web **W** is maintained. As such, the free-span **FS** portion of the web **W** moves at a known speed and is maintained under known tension. In one example, the web **W** moves in the down-web direction **DW** at a speed of 40 feet per minute (fpm) and is maintained under constant tension at one pound per linear inch of width, e.g., if the web extends eighteen inches in the cross-web direction **CW** (Fig. 3), it is maintained under eighteen pounds of tension at all times. As such, the free-span web portion **FS** is maintained under sufficient tension to prevent sagging or any other undesired movement thereof.

The web inspection station **S2** comprises at least one light source **L**, at least one reflected light image capturing system **RL** and at least one transmitted light image capturing system **TL**. The reflected light and transmitted light image capturing systems **RL,TL** are operably coupled to the image processing unit **IPU** as shown, and the light source **L** is optionally coupled to the image processing unit **IPU** to be controlled thereby, but need not be. In general terms, the light source **L** outputs continuous uniform light **I** that is incident on the free-span web portion **FS**. The reflected light image capturing system **RL** receives light **R** from the source **L** that is reflected from the free-span web portion **FS** and derives digital image data that represent the reflected light **R** (referred to herein as reflected light image data

**RD**), while the transmitted light image capturing system **TL** simultaneously receives light **T** from the source **L** that is transmitted through the free-span web portion **FS** and derives digital image data that represent the transmitted light **T** (referred to herein as “transmitted light image data **TD**”). It can be seen in Figure 2 that the image data **RD,TD** are input to the image processing unit **IPU** for real-time web defect detection and classification in accordance with the present development.

Figure 2 illustrates a desirable configuration for the light source **L** and image capturing systems **RL,TL** in order to implement the method and apparatus of the real-time web inspection development. More particularly, the light **I** from source **L** is incident on the free-span web portion **FS** at an angle  $x$  relative to a vertical plane **V**. The reflected light image capturing system **RL** is located to receive the reflected light **R** and is thus arranged on the same side of the web **W** and positioned at an angle  $y$  relative to the vertical plane **V**, where one of the angles  $x,y$  is a positive angle and the other is a negative angle. In one preferred embodiment the angles  $x$  and  $y$  are equal but opposite angles, i.e.,  $x = -y$  to provide a “bright-field” system. Alternatively, the angle  $y$  can be made larger (more negative) to provide a “twilight” system, where the reflected light image capturing system **RL** is not directly located in the reflected light field **R**, but is instead somewhat offset therefrom while still being located therein. The transmitted light image capturing system **TL** is located on an opposite side of the web **W** as compared to the reflected light image capturing system **RL** and is preferably arranged at an angle  $z$  relative to the vertical plane **V** so as to be directly aligned with the light source **L** and, more particularly, the light **I** output thereby, i.e., the lens or other light input to the transmitted light image capturing system **TL** is directly aligned with the axis on which the light **I** is output from source **L**. Thus, as shown,  $x = z$  so that the transmitted light image capturing



system **TL** lies 180 degrees from the light source **L** and incident light **I** so as to receive the transmitted portion **T** of the light **I** that passes directly through the free-span web portion **FS**. As shown in Figure 2, the light source **L** and image capturing systems **RL,TL** are arranged so that **x=15** degrees; **y=-15** degrees; and, **z=15** degrees, but it is not intended that the development be limited to these angles. Also, the illustrated example shows the light **I** from source **L** incident on the web upper surface **WU**, with the reflected light image capturing system **RL** arranged to capture light **R** reflected from the web upper surface **WU**. The light source **L** can alternatively be arranged to project light **I** at the lower web surface **WL** and the reflected light image capturing system **RL** would then be positioned to capture light **R** reflected from the lower web surface, with the transmitted light image capturing system **TL** being located on the opposite side of the web **W** to capture the transmitted light **T**.

The reflected light image capturing system **RL** and transmitted light image capturing system **TL** must be registered with each other to ensure that the images derived respectively thereby correspond to each other, i.e., to ensure that the systems **RL,TL** are simultaneously deriving real-time images of the exact same region of the free-span web portion **FS** in both down-web and cross-web terms. This registration can be accomplished in a variety of different ways. In one example, the web **W** is provided with known test patterns thereon, and the position of one or both image capturing systems **RL,TL** is adjusted until the images output by the systems **RL,TL** are known to be in alignment with each other. Regardless of the registration method used, it is most preferred that the image capturing systems be exactly registered with each other on a pixel-by-pixel basis in both the down web direction **DW** and cross-web direction **CW**. One-pixel deviations in both the down-

web direction **DW** and cross-web direction **CW** are within acceptable tolerance limits. In one embodiment, the reflected light image capturing system **RL** and transmitted light image capturing system **TL** are registered with each other with a tolerance of  $\pm 1$  pixel in both the down-web and cross-web directions **DW,CW**, wherein the pixels are sized at 25 microns down-web and 25 microns cross-web.

Figure 3 diagrammatically illustrates the web inspection station **S2** and a web inspection method in accordance with the present development. In the illustrated embodiment, the reflected light image capturing system **RL** comprises at least one and, preferably, a plurality of reflected light image capturing cameras **R1-R4** spaced laterally across the web **W** in the cross-web direction **CW**. Likewise, the transmitted light image capturing system **TL** comprises at least one and, preferably, a plurality of transmitted light image capturing cameras **T1-T4** spaced laterally across the web **W** in the cross-web direction **CW**. The cameras **R1-R4** correspond respectively to the cameras **T1-T4** so that corresponding pairs of cameras **R1,T1; R2,T2; R3,T3; R4,T4** are defined, and the constituents of each pair are registered with each other as described above in terms of both down-web and cross-web imaging locations so that they image the exact same location of the web **W**, within the  $\pm 1$  pixel down-web and  $\pm 1$  pixel cross-web tolerance noted above. The imaging fields for the cameras **R1-R4** typically overlap each other in the cross-web direction **CW** and the imaging fields for the cameras **T1-T4** typically overlap each other in the cross-web direction **CW** to ensure the full cross-web width of the web **W** is imaged without gaps. Although each group of cameras **R1-R4** and **T1-T4** is shown as including four cameras, this is not intended to limit the development in any way, and more or less cameras can be used as necessary and/or desired.

The reflected light image cameras **R1-R4** are preferably also registered with

each other so that the images derived thereby represent an entire cross-web width of the web **W** having a uniform down-web position. Likewise, the transmitted light image cameras **T1-T4** are preferably also registered with each other so that the images derived thereby represent an entire cross-web width of the web **W** having a uniform down-web position. In the illustrated embodiment, the cameras **R1-R4** and **T1-T4** are each line-scan CCD cameras so that, when the registration operation is complete, the images derived by the cameras **R1-R4** and the cameras **T1-T4** represent a 1 x m row of pixels, where m is the number of pixels extending in the cross-web direction **CW** (which varies depending upon the actual width of the web **W**, the number of cameras and the scanning resolution). It is also preferred that the light source **L** be defined by a light-line that outputs a light pattern **I** that extends laterally across the entire width of the web **W** in the cross-web direction **CW**, but that extends only minimally in the down-web direction **DW**. One suitable light source **L** is a fiber-optic light line, although it is not intended that the development be limited to same.

With continuing reference to Figure 3, the image processing unit **IPU** receives the reflected light image data **RD** and the transmitted light image data **TD** derived by each camera **R1-R4, T1-T4**. A step or means **20** merges the cameras signals for each corresponding pair of cameras **R1, T1; R2, T2; R3, T3; R4, T4** in real-time and outputs respective merged reflected/transmitted image data signals **RT1, RT2, RT3, RT4**.

The merged reflected/transmitted image data signals **RT1 – RT4** are input to a defect identification step or means **30**. Preferably, the unmerged original image data **RD** and **TD** are also input to the defect identification step or means **30**. The defect identification step/means **30** analyzes the input data signals **RT1-RT4**, (and

also the unmerged signals **RD,TD** if available) and flags any portion thereof as representing a defect if the data vary from known ranges for a non-defective web.

Defect data **DD** representing web defects as identified by defect identification step/means **30** are input to a defect feature analysis step or means **40** that derives defect feature parameters for each web defect represented in the data **DD**. In one example, the defect feature analysis step/means **40** derives a list of defect features such as cross-web dimension, down-web dimension, average luminance, maximum and minimum luminance, luminance rate-of-change data, defect shape (e.g., circular, elliptical, etc.), defect location within the web in terms of the cross-web position, and the like. The defect feature analysis step/means **40** is able to derive many defect feature parameters based upon the merged data **RT1 – RT4** that would not be derivable based upon only the reflected data **RD** or only the transmitted data **TD**. With the combined reflected/transmitted light web imaging method described herein, it becomes possible to distinguish defects that appear similar in one lighting configuration, but that appear different in the other lighting configuration.

For each web defect represented by the data **DD**, the defect feature analysis step/means **40** outputs defect feature data **DFD** to a defect feature database step or means **50**. The defect feature data **DFD** for each web defect are input to the defect feature database **50**, which can be a look-up table, histogram matching algorithm, or other database matching means/operation, and the defect feature database **50** outputs a defect classification output value **60** that describes the defect as being a particular type of defect, e.g., surface dirt, an internal bubble, a scratch, a dimple, a bump, etc. The defect classification output value **60** is used by the image processing unit **IPU** to control the web marking/defect culling station **S3,S3'** depending upon the type or defect. For example, if the web **W** is intended for a

high-performance application, the image processing unit can control the web marking/defect culling station **S3,S3'** to mark the relevant portion of the web as defect and or to cull the defective portion from the web. On the other hand, if the web is intended for a low-performance application and the defect value **60** indicates a minor defect, the image processing unit **IPU** can control the web marking/defect culling station **S3,S3'** to take no action.

The image processing unit **IPU** is provided by any suitable circuit and/or programmed computing apparatus suitable for digital image processing such as a dedicated circuit or a specially programmed personal computer. Suitable image processing units **IPU** are available commercially from Cognex Corporation, Natick, MA (one such unit was formerly sold under the tradename ISYS 2000), and other imaging processing units from the same or other sources can be used.

As used herein, the term "real-time" is intended to mean processing data without off-line storage thereof and subsequent retrieval of the data for later processing so that the merged reflected/transmitted light data signals **RT1-RT4** are immediately available for processing before the relevant portion of the web **W** passes through the web marking/defect culling station **S3,S3'**.

Modifications and alterations will occur to those of ordinary skill in the art, and it is intended that the following claims be construed literally and/or according to the doctrine of equivalents to encompass all such modifications and alterations to the fullest extent possible.

## **CLAIMS**